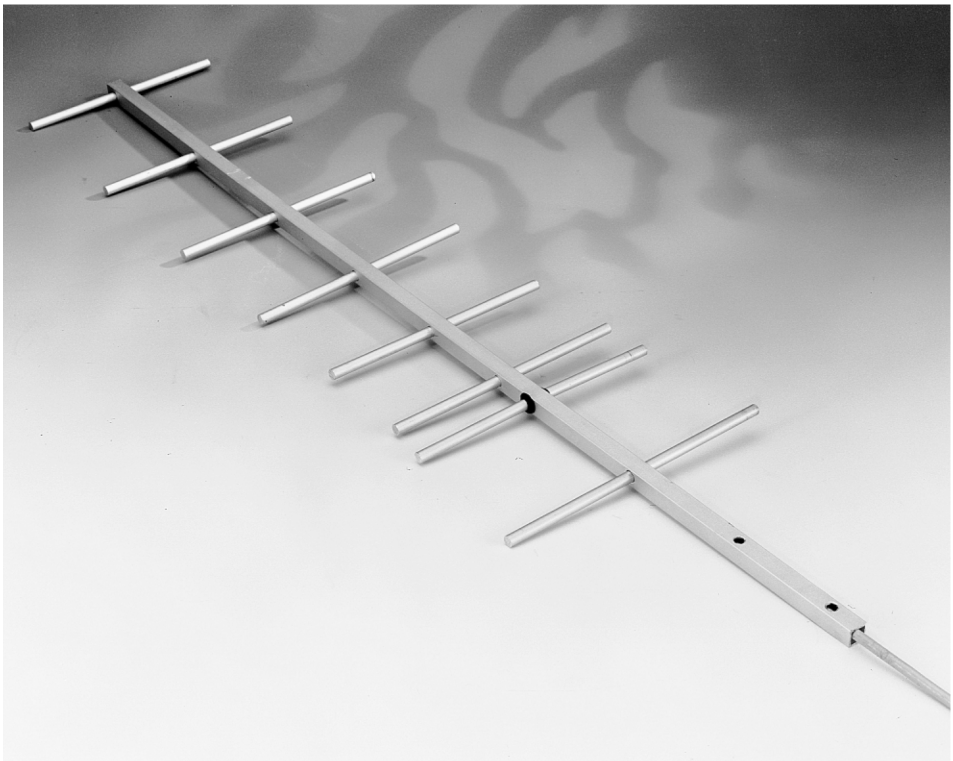
A Yagi aerial for 900-MHz GSM

a fixed antenna for better connections

Although the adverts would have you think that you can use your mobile phone absolutely everywhere, probably every owner of a GSM phone has experienced situations in which the signal quality was hardly worth the name, or the phone simply could not find a transponder. The fixed external antenna presented here might be a help in such situations, since it extends the range of a GSM phone by many kilometres.



You can find them in the Alps, in border regions and in the middle of the countryside — those notorious regions in which even a passable mobile connection is still a pipe dream, and will probably remain so. However, if you mainly use your GSM phone in a fixed location, you can remedy such problems with an external fixed antenna. Such an antenna is the subject of this article. It extends the range of the GSM phone and improves the quality of the data transfer between the phone and your preferred transponder.

A YAGI ANTENNA FOR UHF

It's no particular problem to select a suitable type of antenna from the many different sorts that are available. First off, it should be compact, robust, inexpensive and easy to build. Next, it should be directional and have a good gain figure, and it only has to work over a narrow frequency band. Given these requirements, and considering that GSM mobile phones use transmission frequencies in the microwave region at around 900 MHz, there is only one choice: a Yagi antenna. Thanks to the relatively short wavelength (λ = 33.33 cm), we can easily construct a 'long' Yagi that promises to have respectable gain. (A Yagi antenna that is longer than around one wavelength is generally said to be 'long'; otherwise it is 'short'.)

A Yagi antenna always consists of three different types of elements. The first of these is the driven element, which is a half wave dipole. Put simply, its job is to convert the electric field between its far ends into a current at its centre (or the other way around, since almost any antenna can be used for both reception and transmission). At the centre of the dipole is the feed point, where the antenna cable is attached. The driven element can be built in various ways. This simplest sort is a straight or 'open' dipole. This has the considerable advantage that the impedance at its feed point is nearly 75 Ω, which corresponds roughly to the antenna impedance of the GSM set (50 Ω). Of course, a Yagi antenna is balanced (symmetrical), and if an (unbalanced) 75-Ω coaxial cable is connected directly to the antenna then half of the antenna is effectively earthed, which reduces its gain. A balanced antenna feeder cable, however, has a typical impedance of 240-300 Ω. To be sure, a folded dipole (consisting of two closely spaced, parallel half-wave sections

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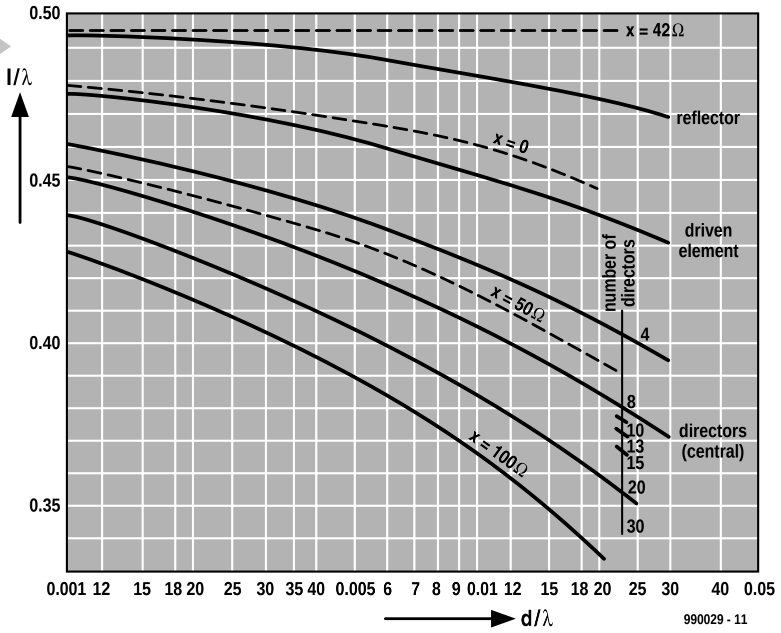

Figure 1. Optimum element lengths as a function of their diameter.

joined at the far ends) could be used for the driven element, and it has a typical feed point impedance of 240 Ω. However, this impedance would still have to be converted to the required value of 75 Ω.

In the first case, all that is needed is a balanced-to-unbalanced converter (a balun), while in the second case both a balun and an impedance converter are necessary. There are many ways to construct a combined balun and impedance converter, but none of them meet one of the most important requirements for the antenna, which that it be mechanically robust. A compact balun, as shown in **Figure 4**, appears by contrast to be ideal for this application: it can placed inside the boom that supports the antenna elements, and it can be easily constructed by winding a 10 to 15 cm length of UHF flat cable (60 Ω impedance; the small difference with 75Ω is not important) into a coil. The way that this balun works is easy to explain. It acts as a choke for unbalanced currents, while allowing balanced currents to pass unhindered. With this balun, an open dipole can be used as the driven element in the GSM Yagi antenna. Note that the balun is not absolutely necessary, but it allows the full gain of the antenna to be realized.

The second type of element is the director. A Yagi antenna has several director elements arranged in a row, in front of and parallel to the driven element. The distance from the reflector (behind the driven element) to the last director element is the length of the antenna, which determines its gain. The distance between the individual director elements is less important, but it should be less than 0.4λ.

So far, what we have is an antenna consisting of a number of equal-sized elements with constant spacing. This is called a plain Yagi. Numerous experiments have however proven that the gain of a Yagi antenna can be increased if the lengths of the elements and the distances between the elements are not constant. Such an antenna is called a tapered Yagi. The gain of a tapered Yagi lies 1 to 2 dB higher than that of an equivalent plain Yagi, so that nowadays only tapered Yagis are used. It is very difficult to compute the optimum values for the element lengths and spacings, so most such antennas are designed from charts and tables.

The third and last type of antenna element is the reflector. This is placed behind the driven element (opposite the director elements) to suppress the radiation or reception of signals in the backward direction. It reflects the signals to the front and thereby increases the gain.

TAKING STOCK

Before we can determine the optimum values for the element lengths and locations, we must decide on the length of the antenna. The antenna described here has six director elements and thus a length of 1.54λ (51.3 cm), according to **Table 1**. The theoretical maximum gain of such an antenna is around 11.5 dB. A longer antenna would of course be possible, but the gain increases only relatively slowly with increasing length, reaching roughly 16 dB at 7λ (Table 1 simply stops at this point). The middle column of Table 1 shows the spacing of the successive elements. You can see that the element spacing increases with the distance away from the driven element, but it never exceeds 0.4λ. Table 2 lists the full specifications of the 900 MHz GSM antenna, including the lengths and spacings of all the elements. The optimum element spacings, taken from Table 1, are shown in the second column.

To determine the optimum lengths of the elements, we have to use the chart shown in **Figure 1**. The cross-sectional area is a factor here, since the larger this is the shorter the elements must be. The elements become progressively shorter from the reflector to the final director. The chart shown in **Figure 2** indicates the proper lengths of the director elements according to their positions with respect to the driven element. For the prototype antenna, I used solid aluminium round stock with a diameter of 6 mm (0.018λ). The optimum element lengths for this diameter are listed in the third column of **Table 2**.

Up to now I haven't said anything about the antenna boom, which supports the elements of the antenna. It has a marginal influence on the dimensions of the elements. Its cross-sectional shape is not important. The elements can be attached to the boom in various ways, either insulated from the boom or in electrical contact with the boom. If the elements are mounted such that they are separated from the boom by more than half of the diameter (or width) of the boom, the influence of the boom is negligible, regardless of whether the mounting is insulated or conductive. However, if the elements pass through the boom and are electrically attached to the boom, as is the case with our antenna, then they must be made somewhat longer. The correc-

Table 1. Optimum element spacings

Element	***Spacing in λ***	***Antenna length in λ***
Reflector	***0.240***	
Dipole		
1. Director	*0.075*	
2. Director	*0.180*	
3. Director	*0.215*	
4. Director	*0.250*	
5. Director	*0.280*	
6. Director	*0.300*	*1.54*
7. Director	*0.315*	*1.88*
8. Director	*0.330*	*2.19*
9. Director	*0.345*	*2.53*
10. Director	*0.360*	*2.89*
11. Director	*0.375*	*3.27*
12. Director	*0.385*	*3.65*
13. Director	*0.390*	*4.05*
14. Director	*0.395*	*4.44*
15. Director	*0.400*	*4.84*
16. Director	*0.400*	*5.24*
17. Director	*0.400*	*5.64*
18. Director	*0.400*	*6.04*
19. Director	*0.400*	*6.44*
20. Director	*0.400*	*6.84*

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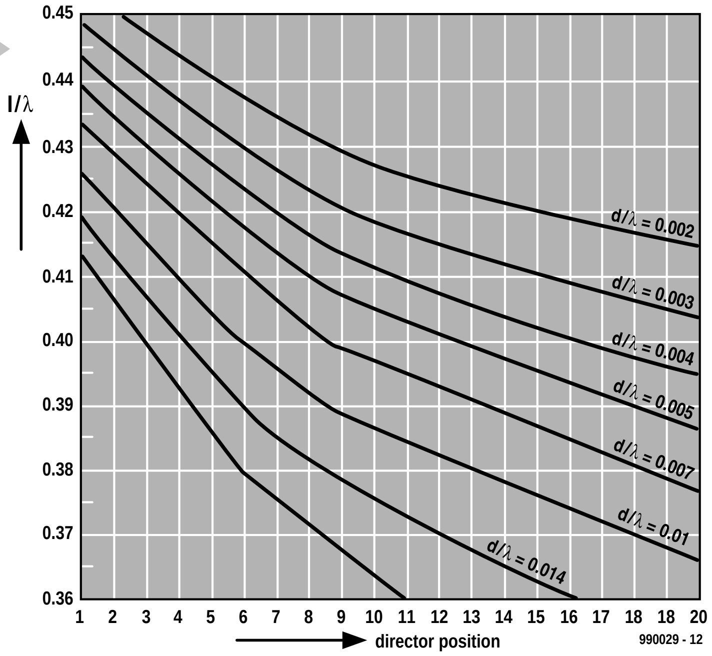

Figure 2. The lengths of the director elements depend on how they are mounted.

tion factor is shown in **Table 3** as a function of the width of the boom. It is easy to understand why this correction is necessary, since the conductive boom reduces the effective electrical length of the elements. This means however that it is important to ensure reliable and durable electrical contact between the boom and the elements!

To construct the antenna boom, I used a length of aluminium square box-section stock with an edge dimension (width) of 10 mm (0.03 (). This and the round stock for the elements are available in every DIY home improvement shop. By the way, it doesn’t particularly matter whether you use anodized or plain aluminium. This is because a bare aluminium surface quickly oxidizes when it is exposed to the elements, forming an oxide layer that protects the underlying metal from further weathering.

In any case, the fourth column in Table 2 lists the final lengths of the elements after the addition of a correction factor of 5.3 mm. Finally, **Figure 3** shows a dimensioned drawing of the full 900 MHz GSM antenna, together with a number of construction details.

CONSTRUCTION

Now for some construction hints. The boom should be mounted by attaching it to a mast or bracket behind the reflector element. Thanks to the light weight and low wind load of the antenna, this can be easily done. Other mounting arrangements might possibly disrupt the operation of the antenna. For this reason, you should be sure to make the boom long enough to allow for mounting the antenna.

To attach the director elements, first carefully measure and mark their positions along the boom, centre punch the marked locations and then drill 6-mm diameter holes through the boom at each location. In addition, drill a small hole in the lateral face of the boom (parallel to the element axis)at each location. This hole should be just large enough to pass a B2.2 × 4 sheet-metal screw (see the top detail in **Figure 3**). Later on, you can file each of these holes into an oval shape along the element axis, to allow the elements to be precisely centred.

Now insert each of the director elements into the boom and precisely mark the middle point of each element, using the point of a sheet metal screw pressed into the previously described lateral holes. Remove the director elements and drill 2-mm diam-

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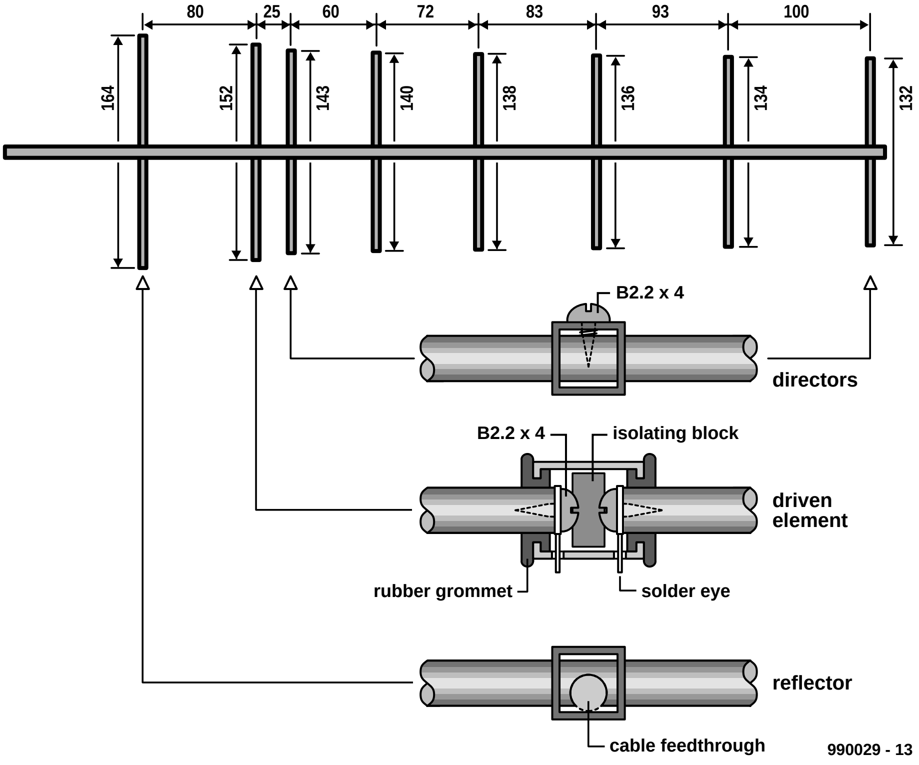

Figure 3. The dimensions of the 900 MHz GSM Yagi antenna, with construction details.

eter holes through them at the marked middle points. These will be used later for the fastening screws.

A 6 mm hole must also be drilled in the boom for the reflector element. However, instead of drilling the middle of the reflector element for a mounting screw, you must file a round notch in it that is just big enough to pass the antenna cable (see the bottom detail in **Figure 3**). Before doing this, check that the reflector element passes readily through its mounting hole in the boom. There is not a lot of material left after the notch is filed, and the reflector element can easily break if too much force is applied to it. If the fit with the mounting hole is too loose, you can screw a small sheet-metal screw into the gap between the element and the boom to secure it and provide a good electrical contact. Do this only after the antenna is fully assembled.

Fitting the driven element requires a certain amount of manual dexterity. This element requires 8-mm diameter mounting holes in the boom. Cut the element exactly through the middle, file the cut ends flat and drill 2-mm diameter holes into the ends. Make these holes deep enough to receive fixing screws for a set of solder lugs (see the middle detail in **Figure 3**).

The driven element is insulated from the boom by a pair of rubber grommets having an inner diameter 6 mm and an outer diameter 8 mm. If necessary, trim the grommets with a knife to obtain a snug fit between the driven element and the boom. It should not be necessary to force the element sections into the boom.

Now it's time to prepare the balun and the coaxial antenna cable (RG58U). First, try to work the end of the coaxial cable past the reflector element and up to the mounting hole for the driven element. Once you have managed this, pull the end of the cable through one of the mounting openings and strip off about 3 cm of the outer insulation. Then remove about 1 cm of insulation from the inner conductor. Twist each of the conductors into a pigtail, and then cover and seal the end of the outer insulation with a length of heat-shrink tubing. Solder the leads of the cable to the leads of one end of the tightly coiled balun cable, and insulate these joints with heat-shrink tubing as well. Separate the leads of the balun cable at the other end for a few centimetres, strip the ends and solder them to the solder lugs. Cover the joints with heat-shrink tubing, so that only the rings of the solder lugs remain exposed.

Now carefully push the balun into the boom, and pass one of its leads through the opposite opening. Insert the previously prepared grommets into the openings, and fasten the solder lugs to the ends of the driven element sections. Finally, insert the two halves of the driven element into the boom — but before doing this, you must prepare an insulator that sits between the two ends of the driven element. You should use a 2 mm thick Teflon disk; this can best be made using a piece of the inner insulation from a 'thick' HF transmitter cable like RG213.

Once the driven element is mounted in the boom, measure its overall length and then reduce it to the correct length (which can be somewhat tedious). After you have mounted and centred the director elements and attached a connector to the far end of the antenna cable, you can attach the antenna to its mount. The GSM Yagi antenna is now ready for use. It works very well with a GSM phone as a base station for a private or mixed DECT telephone installation.

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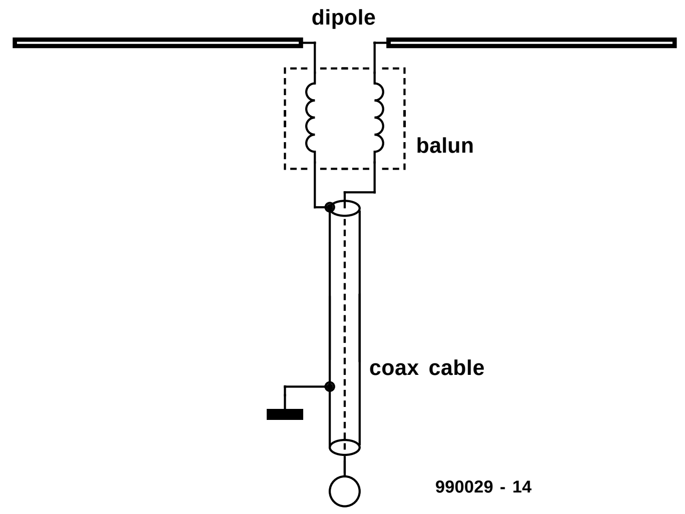

Figure 4. Balun to match the cable impedance.

Table 2. Calculation of Yagi antenna parts

Basics

Frequency	*900 MHz*
Wavelength λ	*33.33 cm*
Antenna length	*1.54 λ* *51.3 cm*
Element diameter	*0.018 λ* *6 mm*
Boom side length	*0.03 λ* *10 mm*

Element	***Distance (Table 1)***		***Length (Figs. 1/2)***		***Length (Fig. 3)***
Reflector	*0.240 λ*	*80 mm*	*0.476 λ*	*159 mm*	*164 mm*
Dipole			*0.441 λ*	*147 mm*	*152 mm*
1. Director	*0.075 λ*	*25 mm*	*0.412 λ*	*137 mm*	*143 mm*
2. Director	*0.180 λ*	*60 mm*	*0.405 λ*	*135 mm*	*140 mm*
3. Director	*0.215 λ*	*72 mm*	*0.398 λ*	*133 mm*	*138 mm*
4. Director	*0.250 λ*	*83 mm*	*0.392 λ*	*131 mm*	*136 mm*
5. Director	*0.280 λ*	*93 mm*	*0.386 λ*	*129 mm*	*134 mm*
6. Director	*0.300 λ*	*100 mm*	*0.380 λ*	*127 mm*	*132 mm*

Table 3. Element length correction due to insertion in boom

D in λ	***Correction Δl in λ***
0.010	*+0.003*
0.015	*+0.005*
0.020	*+0.008*
0.025	*+0.010*
0.030	*+0.016*
0.040	*+0.026*
0.050	*+0.038*

Reference:

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Stuttgart 1984, Germany